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WATER SOURCE HEAT PUMPS FOR GREENHOUSE SOIL COOLING

FINAL REPORT

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ABSTRACT

Water-source heat pumps were used to maintain greenhouse soil temperature, in the range of 12°C to 15°C, for Alstroemeria production. Chilled water from the heat pumps is circulated through a system of polyethylene pipes buried in the growing beds, to effectively cool the soil.

INTRODUCTION

In an attempt to diversify and grow flowers which are in high demand, growers are looking to produce certain exotic flowers which require unique growing conditions. One example is the Alstroemerias. These flowers originated in South America and have been grown in hot houses and backyard gardens for a number of years. They are desired for their vivid colours and their good keeping qualities.

Alstroemeria, also known as The Peruvian Lily, is an extrememly vigorous plant. The plant itself consists of a white fleshy rhizome that will produce aerial shoots and a root system. These aerial shoots can be vegetative or reproductive. If the plants are grown continuously at about 12 - 15°C soil temperature, the plant will continue to flower regardless of air temperature and photoperiod. These latter two factors are considered secondary to the importance of cool soil temperatures.

Alstroemeria production is still relatively new to the greenhouse industry. Some controversy still exists as to the direct benefits of planned soil cooling. This project was set up to evaluate a mechanical soil cooling system for continuous year round Alstroemeria production.

OBJECTIVE

To determine the performance and economics of using water-to-water heat pumps to provide soil cooling in a greenhouse for Alstroemeria production.

TEST FACILITIES

A heat pump soil cooling system was installed in two greenhouses each with dimensions of 16 m by 61 m. Combined these greenhouses have a growing area of 1952 m^2. These greenhouses are older wooden greenhouses, covered by double poly, air-inflated glazing.

The cooling system consists of three 5 Ton water-to-water heat pumps, WaterFurnace model WHP613. The heat sink is well water from three 10 m deep, gravel pack supply wells. Water in the Leamington area is abundant and fairly close to the surface. The water from the heat pumps is discharged into a ditch at the back of the greenhouses.

The soil loop buried in the greenhouse soil consists of 25 mm I.D., 517 kPa polyethylene pipe connected with barbed fittings and stainless steel gear clamps. The greenhouse soil loop is a closed loop system. The cooled water from the heat pumps is pumped by a Gould No. XSH07 centrifugal pump to two identical centrifugal pumps, one pumping to each greenhouse. After passing through the soil loop, this water returns back to the heat pumps. The heat pump/greenhouse soil loop, is a closed loop with the cooled water, treated to prevent algae, merely circulating around this circuit.

The main loop supply and return are buried down the centre of the greenhouses to the mid-length point. Here the supply line branches off into four circuits, each with a gate valve. In this manner four quadrants or zones were setup in each greenhouse. This allows for isolating quadrants for soil preparation and subsequent replanting. Loop headers extend from this central point out to the sides of the greenhouse. Figure #1 illustrates graphically the layout of this system.

The Alstroemerias all grown in rows spaced 600 mm apart centred on beds 1200 mm wide. A narrow walkway separates the beds. Each row of Alstroemerias has a single loop going down one side and back up the other. With this lay-out, uniform soil temperatures are expected for individual plant rows.

In order to be assured of constant and uniform flow of water through all the soil cooling loops, reverse-return flow plumbing is essential. With this layout all flow paths are of equal length and the resistance to flow is equalized. The reverse-return flow piping system is shown in Figure #3.

Prior to planting, the soil is deep spaded to loosen the soil and incorporate straw as a soil amendment. Steam sterilization is then carried out and the soil cultivated, ready for planting. The polyethylene soil loop is then buried, by hand, to a depth of 150 mm. Since a crop is grown for a period of two years, the loop does not have to be moved during that time. When a new crop of Alstroemerias is started, the ground loop has to be temporarily removed to allow for the deep spading and steam sterilization.

Deeper placement of the soil loop would eliminate the need to remove and reposition the loop every two years. However, deeper loop placements was felt to be a disadvantage because more soil mass would have to be cooled. It was also felt that possible damage might be sustained by the polyethylene pipe when steam sterilization was carried out. The loop was instead put at the same level as the rhizomes of the plant to minimize the soil mass; See Figure 4.

In the cooling mode, water from the wells is pumped by the well pump to two booster pumps, then to the heat pumps on demand. Each heat pump requires approximately 0.6 L/s. The heat pumps extract heat from the greenhouse soil loop and reject it to the well water. This warmed well water is discharged into a ditch located behind the greenhouse.

The three heat pumps are connected in parallel to each of the following: well water supply, discharge, loop supply, and loop return lines. The heat pumps are manually turned on when the grower notices soil temperatures rising above the desired levels. Once on, each heat pump is controlled by a programmable thermostat which senses soil temperature 150 mm deep. For the most part the heat pumps were either all on or all off and not staged to come on. At some future date these heat pumps will be controlled by the greenhouse environmental control computer which is in place.

Polystyrene bead insulation is put on the surface of the beds to insulate and reflect solar radiation from the dark soil surface. In the walkways, straw is used to reflect some of the incoming solar radiation.

During the winter months when soil cooling is not required, the heat pumps are switched to the heating mode and warm water from the heat pumps is piped to unit heaters in each greenhouse, to provide heat.

MONITORING

Various parameters were monitored to determine the performance of the system.

Temperatures:

- soil at various depths in the row
- ambient air
- greenhouse air
- well water to heat pumps
- discharge water from heat pumps
- soil loop supply
- soil loop return
- individual loop supply
- individual loop return

T-TYPE THERMOCOUPLES -TO KAYE- DIGISTRIP III DATA LOGGER

Heat Added to Well Water:

- measured with a heat integrator which senses well water supply and discharge temperatures as well as flow rate from an impulse contactor/ water meter.

Electrical Energy Consumption:

- with kilowatthour meter to measure electrical consumption of three heat pumps and soil loop circulation pump and loop booster pumps.

Running Time:

- hour clocks on each heat pump

Solar Insolation:

- with star pyranometer installed horizontally outside the greenhouse.

RESULTS

The heat pump soil cooling system has been in operation for two years. The first year was spent debugging the system with very little data collected. During the second year of testing, namely 1986, the system was monitored extensively.

Figure #5 shows temperatures of various points in the greenhouse as well as solar insolation for July 18, 1986. This particular day was bright, sunny, and hot which is the worst condition which could be expected for the soil cooling system. It can be seen that the soil temperature at the 150 mm depth, in the plant row remains very near 14°C, which is the growers desired temperature. At 0000h the loop supply temperature was 8.2°C while the loop return temperature was 12.6°C. Both these temperatures remained constant until approximately 1300h when they both increased by 1C° over a period of two to four hours. Both these temperatures started to rise approximately four hours after the solar radiation had reached 80% of its maximum for the day. This lag time with respect to solar radiation rise, can be attributed to the soil mass above the soil loop. Over the year, well water supply temperature fluctuated between 13°C and 17°C. Throughout the day the ground loop warms up approximately 4.4C° from the loop supply to the loop return points.

Figure #6 shows graphically average noon soil temperature, plotted once per week, for the whole year. Soil temperatures during the year varied from 11.5°C to 15.7°C. The grower is experimenting on his own with various temperature settings for his Alstroemeria crop. As more experience is gained with Alstroemeria production, the soil temperatures are being fine tuned, to increase flower production per m^2.

Table #1 summarizes the energy consumption, water useage, heat rejected to well water, as well as average daily cost of operation of the system. During the period of active soil cooling, April to September, the daily cost of running the system ranged from a low of $6.14 to a high of $29.47. The higher figure occurs when soil cooling is required 100% of the time. See Table 2.

Since the well pump and two booster pumps were not fed through the monitoring kilowatthour meter, their electrical energy useage was calculated using the following assumptions.

		WELL PUMP	WELL WATER BOOSTER PUMPS x 2
1.	Amperage Draw	7.7 Amps	9.6 Amps (Measured)
2.	Voltage	221 Volts	221 Volts (Measured)

3. Power correction factor 0.8

4. The well pump and booster pumps supply water to eight 5 Ton water-to-water heat pumps in all. For calculations, 3/8 of the energy used to move the water will be used since the test greenhouse has three heat pumps.

Power draw well pump = 221 volts x 7.7 amps
= 1701.7 watts

Power draw booster pumps = 221 volts x 9.6 amps x 2
= 2121.6 watts x 2
= 4243.2 watts

∴ Total power draw = 1701.7 + 4343.2
= 5944.9 watts

Multiply by power correction factor = 5944.9 x 0.8
= 4755.92 watts

3/8 of this = 4755.92 x 3/8
= 1783.47 watts
≈ 1.8 kW

∴ Energy consumed by the well pump and the two booster pumps for the test greenhouses is approximately 1.8 kW/hour of heat pump operation.

To arrive at the kWh used by the pumps in Table #1, the hourly 1.8 kW was multiplied by the highest hours of operation of any of the three heat pumps. See Table 2.

Flow rates of water circulating through the total soil loop were determined to be 3.0 L/s. Flow rates through individual Alstroemeria row loops =

$$\frac{3.0 \text{ L/s}}{2 \text{ Greenhouses} \times 20 \text{ Beds/Greenhouse} \times 2 \text{ Loops/Bed}}$$

$$= \frac{3.0 \text{ L/s}}{80 \text{ Flow Paths}}$$

$$\approx 0.038 \text{ L/s}$$

One observation made by the grower was that the soil temperatures could not be held down at the desired levels in an individual zone of the greenhouse when it was cleaned out for replanting. The absence of plant foliage to intercept the sunlight caused the dark soil surface to absorb a large amount of heat.

Average daily cost of operation for the system range from $6.14 per day during intermittent operation, to a high of $29.47 per day during continuous operation. The cost of electrical energy was based on the farmer's cost of $0.0553/kWh.

ECONOMICS

COST OF THE SYSTEM:

Drilling of 3 water supply wells	$ 4800
Polyethylene pipe, elbows, valves, etc.	3200
Three 5 Ton water-to-water heat pumps	16400
Circulation & booster pumps, well pump	2000
TOTAL	$26400

Fixed cost of the system = $\frac{\$26,400}{1952\ m^2}$

= $\$13.52\ /m^2$

Operating costs: Cooling 40% of time = $\frac{\$6.14\ /day}{1952\ m^2}$

= $\$0.003\ /m^2/day$

Cooling 100% of time = $\frac{\$29.47\ /day}{1952\ m^2}$

= $\$0.015\ /m^2/day$

Operating costs for cooling system range from \$0.003 to \$0.015/ m^2/day with heat pumps operating 40% and 100% running time respectively.

Payback calculations for this system are difficult since the benefits from the system are indirect. The grower feels that the soil cooling system has assured him of a production system that will provide a constant supply of flowers for harvest through-out the year. By manipulating the soil temperature and supplemental lighting he also feels that the flowers can be held back or accelerated to coincide with peak market periods.

CONCLUSIONS

1. This heat pump soil cooling system worked very well maintaining the soil temperature at the proper levels throughout the spring and summer months. During the rest of the year the soil cooling system is used less intensely.

2. Systems that are installed where ground water is not readily available for the heat pumps, would require more capital outlay because a large ground loop would have to be installed.

3. The fact that the greenhouse soil loop is installed shallow, 150 mm deep in the soil, is a benefit because not as much soil mass has to be cooled as with a deeper loop.

4. It appears from the growers observations, that certain cultivars respond differently to soil cooling. That is to say that certain ones benefit more by having cooled soil, - thereby more production.

5. Very few blind shoots have to be pulled when soil cooling is applied to the Alstroemeria crop. Without soil cooling, blind shoots or shoots which will not flower, would have to be removed monthly.

6. Reverse-return flow plumbing is essential to provide uniform flow throughout the entire greenhouse soil loop system.

7. Well water consumption is approximately 0.6 L/s per 5 Ton heat pump when running.

8. Water flow rate through the whole greenhouse soil loop is approximately 3.0 L/s.

9. During winter months when soil cooling is not required, the heat pumps provide base load heating to the greenhouse through fan forced unit heaters.

10. In the spring of 1987 the cooperator added a fourth 5 Ton heat pump to this system, mainly as insurance should one of the three heat pumps fail.

11. In the new greenhouse range slated for Alstroemeria production, the grower has installed the identical soil loop configuration but has added a 50% shade curtain to reduce the solar heat gain by the greenhouse soil.

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Mr. Graham Henderson with Ontario Hydro, Toronto, for supplying the heat integrator used in monitoring.

Mr. Dan Van Hooren, Energy Specialist, with the Agricultural Energy Centre, for assisting with the installation of monitoring equipment and programming of the data logger.

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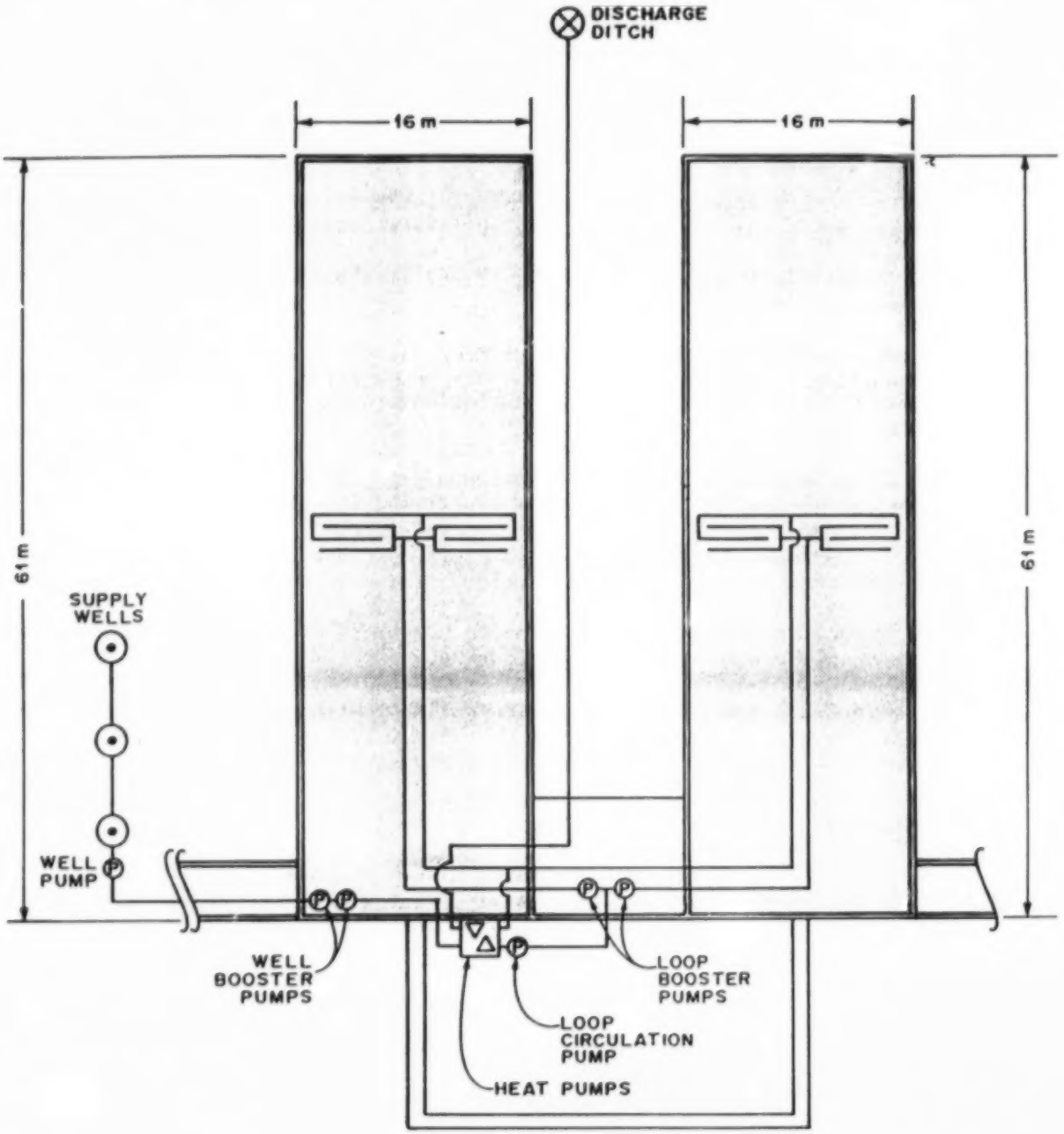

FIGURE 1 — SYSTEM LAYOUT

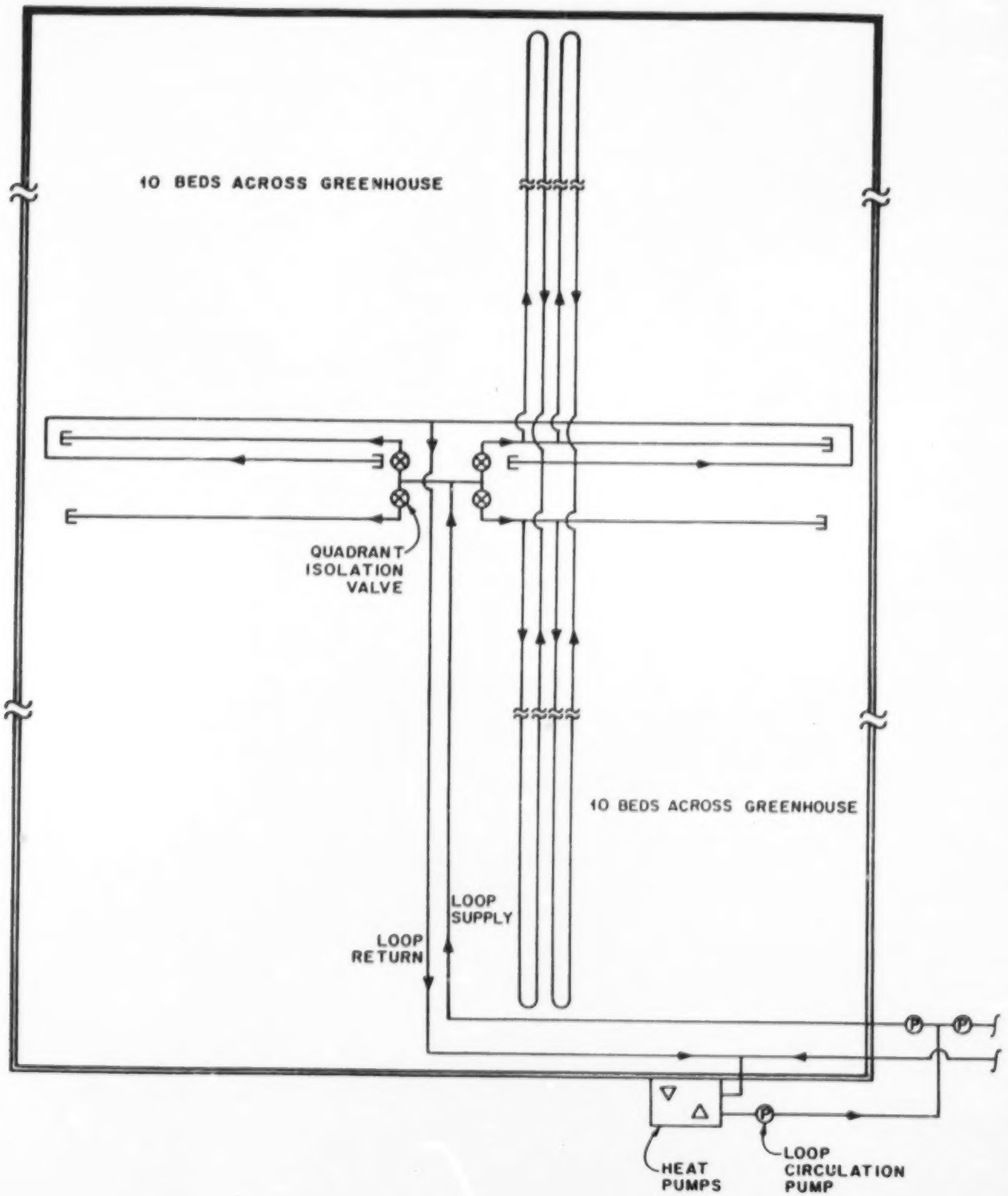

FIGURE 2—SOIL LOOP PLUMBING DETAIL FOR EACH GREENHOUSE

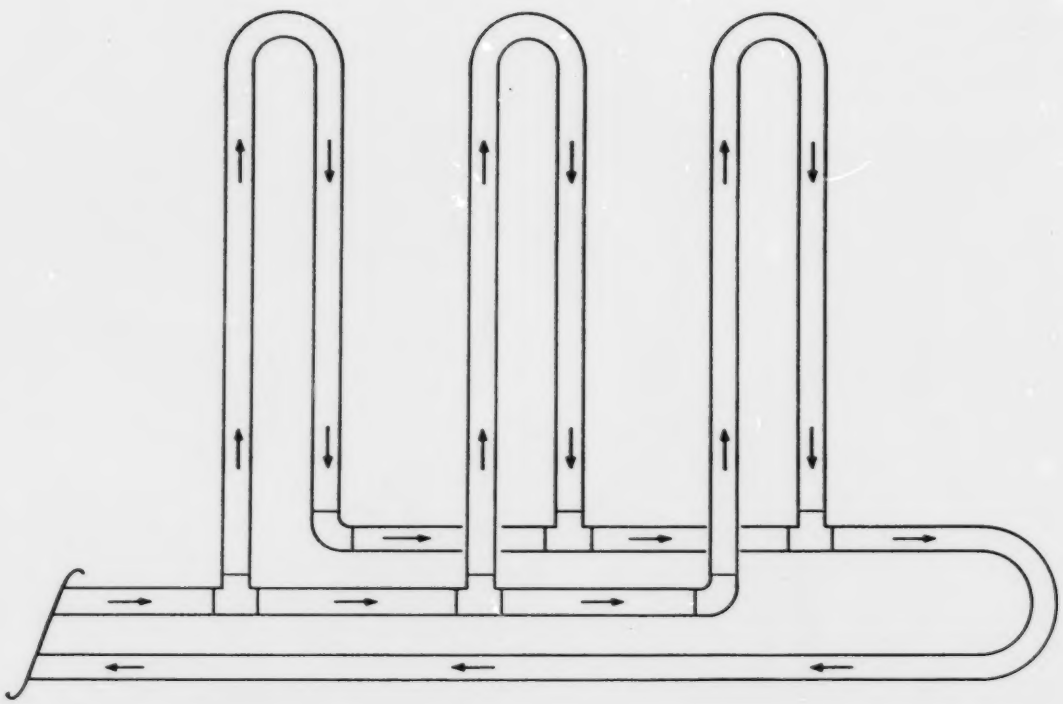

FIGURE 3 — REVERSE-RETURN PIPING SYSTEM

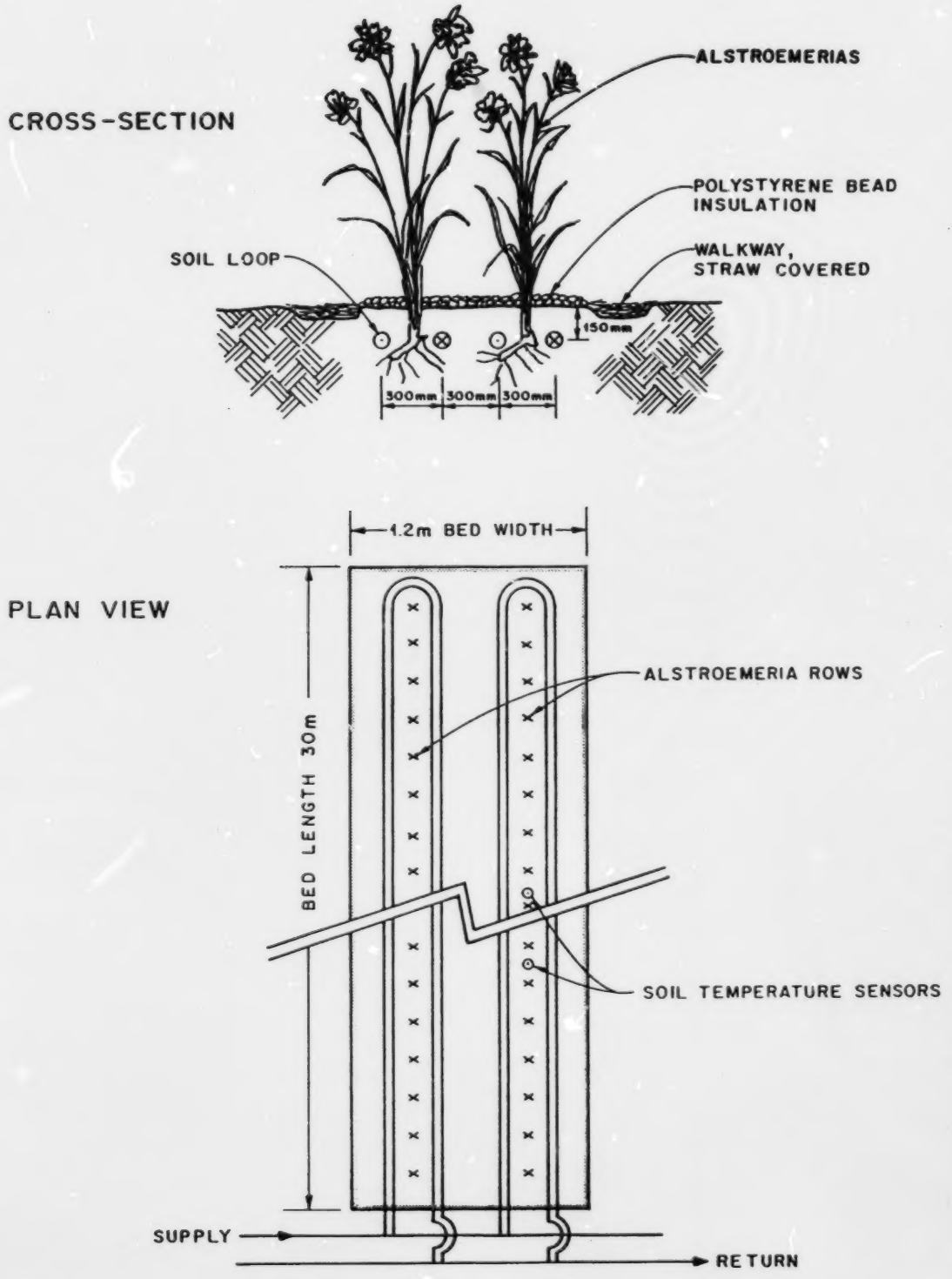

FIGURE 4—SOIL LOOP PLACEMENT IN ALSTROEMERIA BEDS

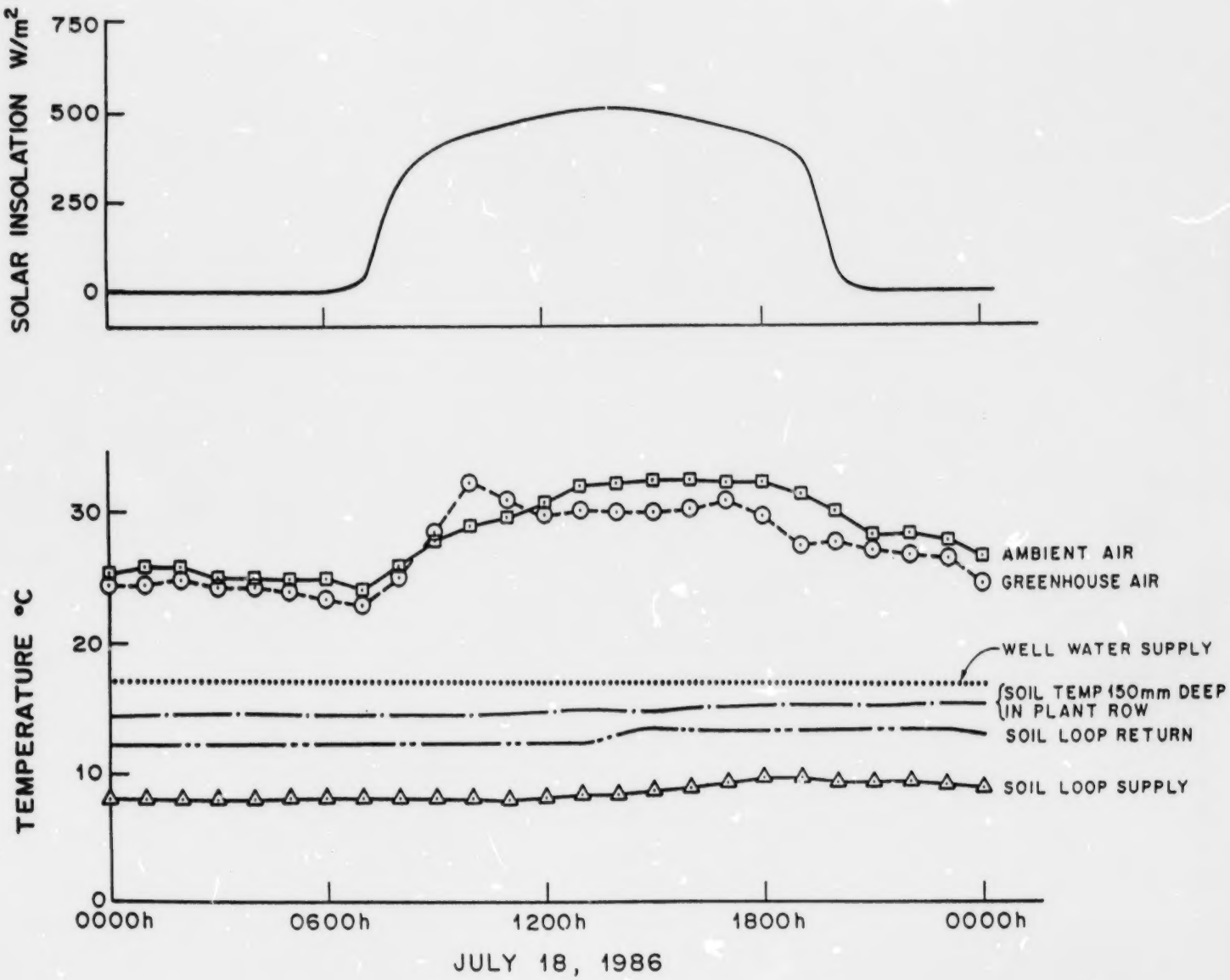

FIGURE 5—SOLAR INSOLATION / TEMPERATURES IN GREENHOUSE

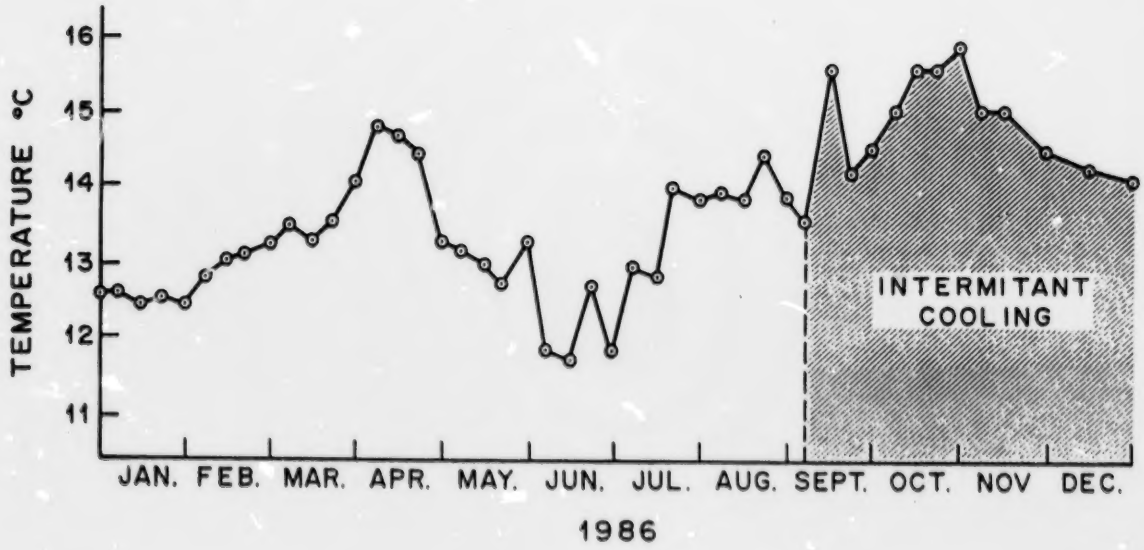

FIGURE 6 — AVERAGE SOIL TEMPERATURES 150 mm DEEP, IN PLANT ROW

TABLE #1 ELECTRICAL CONSUMPTION AND WATER USEAGE

PERIOD ENDING		ELECTRICITY USED H.P.'s LOOP & BOOSTER PUMPS kWh	ELECTRICITY USED WELL & BOOSTER PUMP kWh	TOTAL ELECT'Y kWh	AVERAGE kWH/DAY	COST/DAY $0.0553/kWh	AVERAGE WELL WATER USED/DAY m^3	HEAT REJECTED TO WELL WATER kWh
1986								
APRIL	17							
	29	1970	315	2285	190	$ 10.51	32.4	5512
MAY	07	1820	337	2157	270	14.93	47.8	5509
	14	1850	301	2151	307	16.98	64.6	6169
	20	1700	266	1966	328	18.14	79.2	5497
	27	2740	292	3032	433	23.95	64.5	5517
JUNE	03	2370	301	2671	445	24.61	112.0	7977
	13	3360	432	3792	379	20.96	88.3	11024
	23	3400	432	3822	383	21.18	128.1	11735
JULY	02	2600	358	2958	329	18.19	107.1	8928
	07	1530	193	1723	345	19.08	119.8	5433
	14	2470	308	2778	397	21.95	140.3	9093
	18	1390	171	1561	390	21.57	133.7	4925
	24	2200	263	2463	411	22.73	135.3	7650
AUG.	01	2890	338	3228	404	22.34	117.4	9788
	09	3100	356	3456	432	23.89	107.2	10267
	16	3450	284	3734	533	29.47	121.0	8211
	19	210	124	334	111	6.14	50.7	3671
	27	2820	331	3151	394	21.79	114.7	9624
SEPT.	02	920	106	1026	171	9.46	51.6	3008

TABLE #2 PERCENTAGE HEAT PUMP RUN TIME DURING PREVIOUS INTERVALS

PERIOD ENDING 1986	H.P. #1	H.P. #2	H.P. #3
APRIL 17			
29	18%	61%	60%
MAY 07	31	60	97
14	100	100	48
20	100	62	76
27	96	64	79
JUNE 03	100	100	100
13	100	93	100
23	100	100	100
JULY 02	92	92	92
07	89	89	89
14	100	100	100
18	100	100	100
24	100	100	100
AUG. 01	100	100	100
09	100	100	100
16	93	94	94
19	41	40	40
27	95	96	96
SEPT. 02	41	40	40
INTERMITTENT SOIL COOLING AS REQUIRED			